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Advanced Test Reactor (ATR) Facility 10CFR830 Safety Basis Related to Facility Experiments

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Abstract

The Idaho National Engineering and Environmental Laboratory (INEEL) Advanced Test Reactor (ATR), a DOE Category A reactor, was designed to provide an irradiation test environment for conducting a variety of experiments. The ATR Safety Analysis Report,[1] determined by DOE to meet the requirements of 10 CFR 830, Subpart B, provides versatility in types of experiments that may be conducted. This paper addresses two general types of experiments in the ATR facility and how safety analyses for experiments are related to the ATR safety basis. One type of experiment is more routine and generally represents greater risks; therefore this type of experiment is addressed with more detail in the safety basis. This allows individual safety analyses for these experiments to be more routine and repetitive. The second type of experiment is less defined and is permitted under more general controls. Therefore, individual safety analyses for the second type of experiment tend to be more unique from experiment to experiment. Experiments are also discussed relative to "major modifications" and DOE-STD-1027-92. Application of the USQ process to ATR experiments is also discussed.

Introduction

The Advanced Test Reactor (ATR), designed for the irradiation of experiments, began operation in 1967. The original safety basis addressed the primary irradiation experiments and included a Safety Analysis Report and Operating Limits.

In 1977 the safety basis documents were upgraded to a Design Basis Report and Technical Specifications. The Design Basis Report was prepared using the guidelines of Chapter 15 of the U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants," and the Technical Specifications were based on an American Nuclear Society guide for the development of technical specifications for research reactors. Consideration of experiments was expanded in the 1977 safety basis. The Design Basis Report underwent numerous revisions and the last issue was released in 1994.

In 1989 a major upgrade of the safety basis was initiated. The initial upgrade plans were based largely on guidance per NRC Regulatory Guide 1.70.[2] Upon issuance of DOE Order 5480.22, "Technical Safety Requirements," and DOE Order 5480.23, "Nuclear Safety Analysis Reports," in 1992, the upgrade plans were modified and the end products were Technical Safety Requirements and an upgraded Final Safety Analysis Report that met the requirements of these DOE Orders. This upgraded ATR safety basis was approved by DOE in 1996 and implemented along with its first annual update in 1998. It included significant changes in the type of controls for assuring safety of experiments. After undergoing additional updates, the ATR documented safety analysis (DSA), was determined by DOE in November of 2001 to meet the requirements of 10 CFR 830, Subpart B.[3]

With a power rating of 250 MW, the ATR is the largest operating DOE Category A reactor. It is a light water, low temperature, and low pressure test reactor. The ATR DSA (see Reference 1) is designed to accommodate two general types of irradiation experiments. The predominant type of experiment is a pressurized water loop (PWL) type of experiment that circulates water, at typical pressurized water reactor pressures and temperatures, past specimens being irradiated in the reactor core. PWL experiments have been characterized over many years of experience and the ATR DSA is based on a comprehensive set of analyses of these experiments. The other general type of experiment varies more than the PWL experiments and includes "capsule" experiments irradiated inside the reactor pressure vessel and "canal" experiments in the reactor irradiated fuel storage canal. Capsule experiments are distinct from PWL experiments primarily in that they rely on reactor primary coolant for heat dissipation. By controlling the heat dissipation from capsule experiments, the experiment material temperatures can range from approximately the temperature of the reactor primary coolant up to temperatures representative of gas cooled reactors. Canal experiments generally involve the use of irradiated ATR fuel elements or Co-60 for the irradiation of materials.

ATR Experiment Irradiation Facilities

The ATR was designed to include a variety of irradiation locations in the reactor core and reflector. The ATR core is comprised of 40 fuel elements arranged in a serpentine configuration. Figure 1 is a plan view of the reactor fuel arrangement as well as the available experiment locations. The serpentine core creates a 3 x 3 square array of flux trap regions with associated spaces for experiments. Surrounding the ATR core is a beryllium reflector. The reflector includes numerous cylindrical penetrations, some of which are available for experiments. Sixteen of the largest reflector penetrations are designed to house outer shim control cylinders that are used to help control different regions of the core at different power levels. Two capsule irradiation tanks include additional experiment locations outside the reflector.

PWL Experiment Facilities

The present ATR configuration includes PWL experiments in five of the flux trap regions. The designs of the PWL experiment facilities vary, however, a standard PWL is based on a design temperature of 650 $^{\circ}$F, a design pressure of 2500 psig, and design flow rate of 20-80 gpm.

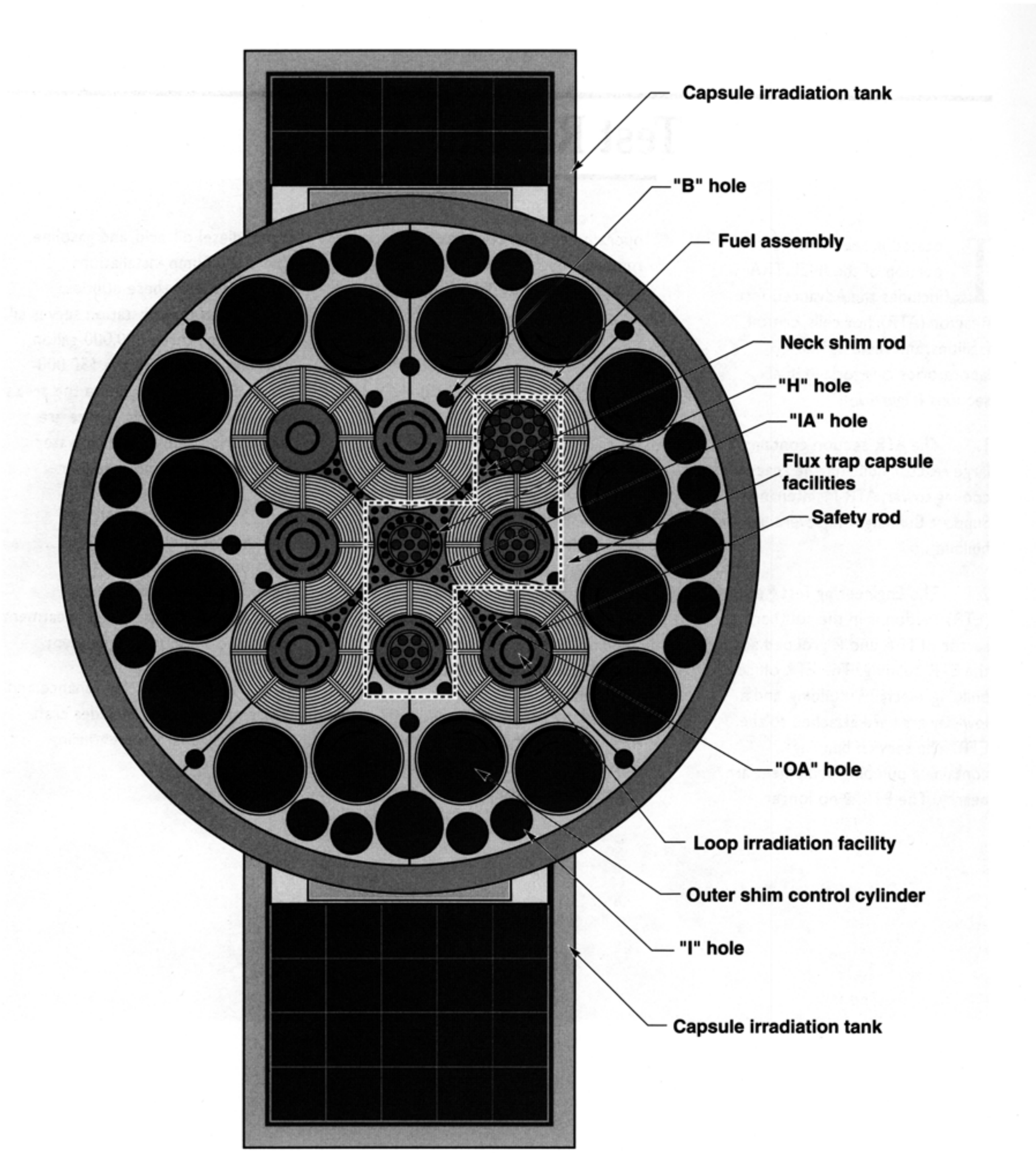

Figure 1. ATR Core Configuration.

Figure 2 depicts the general configuration of a PWL. Double containment is included in each PWL portion of piping inside the reactor vessel.

Capsule and Canal Experiment Facilities

A wide variety of locations and sizes are available for capsule experiments. As shown in Figure 1, four flux traps currently include capsule experiment facilities. Relatively small capsules are depicted in flux trap capsule facilities in Figure 1, however, larger capsules are feasible. In the largest of the four flux traps a capsule experiment facility could approach a diameter of up to approximately 5.2 inches. In addition, Figure 1 identifies available capsule experiment locations as "B, H, I, IA, and OA" holes. The hole diameters for these locations vary from 0.625 to 5.0 inches. Capsule experiment facilities are dependent on the reactor primary coolant for any necessary cooling. As shown in Figure 3, some capsule experiment facilities may include instrument leads as well as flowing gas lines, whereas others may not include any instrumentation or hardware penetrating the reactor vessel.

Canal experiment facilities generally involve placing the target materials to be irradiated inside a container located such that irradiated fuel elements or Co-60 sources provide the radiation. Canal experiments may or may not include instrumentation leads and other equipment devices interfaced with the targets. Safety concerns for canal experiments are usually less critical than those for reactor experiments, however, the safety basis does include canal experiment controls.

Experiment Coverage in the ATR Safety Basis

10 CFR 830 indicates that NRC Regulatory Guide 1.70 is a "safe harbor" acceptable methodology for preparation of a DOE reactor DSA. NRC Regulatory Guide 1.70 was used extensively in the development of the ATR DSA; however, an alternative approach was used for Chapter 10 of the DSA. Since the ATR does not produce steam or electrical power, Chapter 10 of the ATR DSA is devoted to "Experiments and Irradiation Facilities" rather than the normal NRC Regulatory Guide 1.70 subject of "Steam and Power Conversion System." Chapter 10 describes the experiment facilities and clearly denotes that experiments, including experiment handling, can be initiators of significant reactor facility accidents. Experiment cask drop events, for example, can cause reactor accidents. Criticality safety is also an obvious consideration for storage and handling of experiments containing fissile material. The ATR DSA demonstrates that experiments can be conducted within the facility risk envelope, however, it does not include a thorough analysis of each experiment. Consequently, an important DSA commitment is that each experiment is to be supported by a detailed experiment safety analysis (ESA). A DOE approved USQ process is incorporated into each ESA to assure that every experiment is conducted within the approved facility risk envelope. In addition to a required ESA for every experiment in the ATR facility, a core safety assurance package is prepared and approved for every reactor operating cycle. Reactor core safety is tied to the experiments in the reactor, especially those experiments located in the flux traps. The individual experiment safety analyses and core safety assurance package for each reactor cycle provide safety assessments for reactor operations. The individual experiment safety analyses and applicable ATR Technical Safety Requirements[4] (TSR) assure safe experiment activities during reactor outage periods.

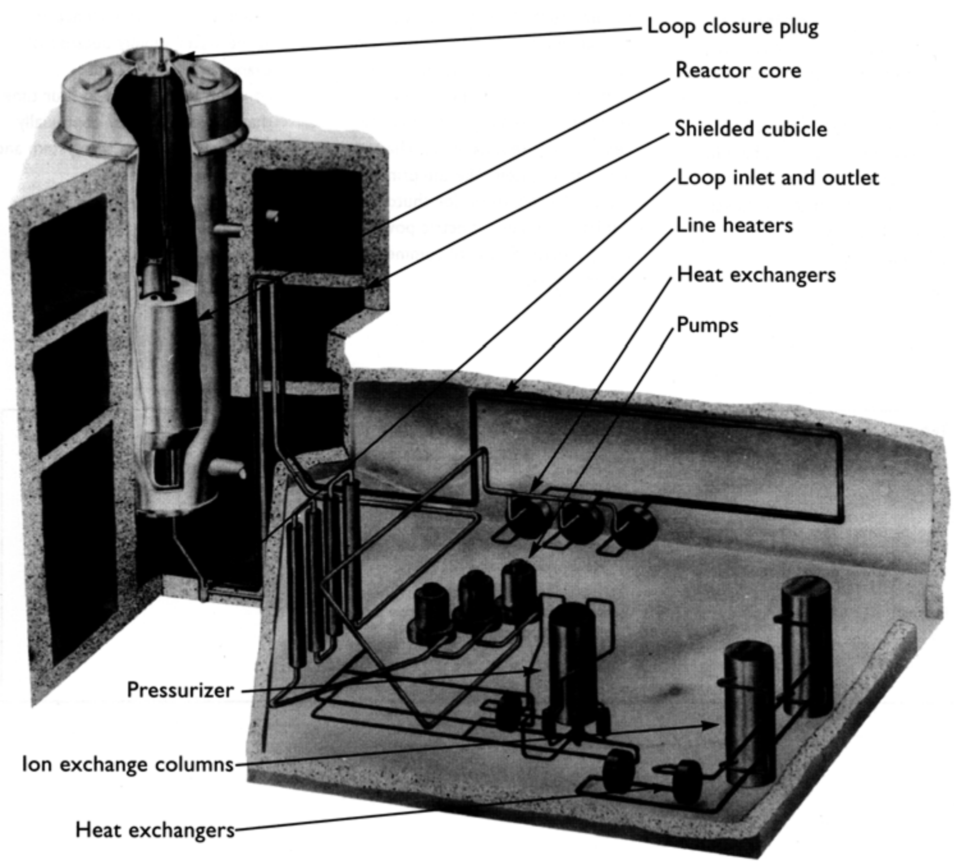

Figure 2. Pressurized Water Loop General Layout.

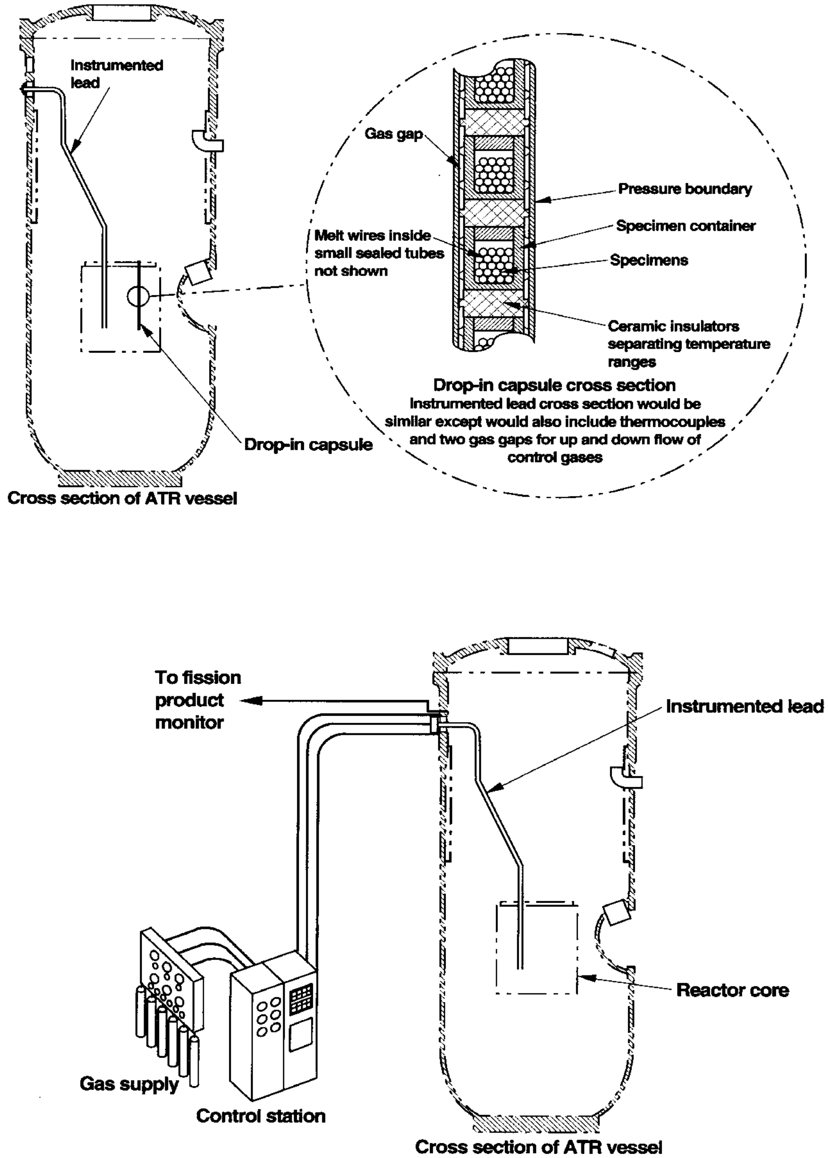

Figure 3. Examples of Capsule Experiment Facilities.

The ATR was designed to conduct primarily the PWL type of experiments. Therefore, from the beginning of the safety analysis efforts, accident analyses were focused more toward the PWL experiments than capsule experiments. The sensitive relationship between the flux traps and the reactor core caused due attention to potential accidents involving the PWL experiments. This sensitivity is demonstrated, for example, by the fact that the flux traps in the ATR exhibit a positive void reactivity coefficient. Sudden voiding of a flux trap would therefore initiate a reactor power transient. Consequently, PWL experiment accidents that could cause voiding of a flux trap have received significant analysis and have tended to be directly addressed in the DSA. One early safety analysis concern was the potential for a PWL primary and secondary pressure boundary to fail in the reactor core region, thus allowing complete voiding of the water areas in the experiment as well as in surrounding areas of the flux trap. This accident is assessed in the ATR DSA as one of the accidents beyond the design basis of the facility and is an example of how accident analyses for PWL experiments are integrated into the DSA. PWL experiments are routinely conducted within well-defined ranges of parameters, thus making it appropriate to include comprehensive coverage of the PWL experiments in the DSA. Capsule experiments, in contrast, are not covered in any significant detail in the DSA and therefore it is incumbent on the individual ESA documents to address the appropriate capsule accident analyses.

In accordance with DOE-STD-1027-92,[5] the ATR is a Hazard Category 1 nuclear facility. The absence or presence of any one experiment does not change this hazard categorization; the radiological source term represented by any one experiment is minor compared to that of the reactor fuel. The dominant hazard represented by the reactor can result in the tendency to overlook the hazards associated with individual experiments upon their removal from the reactor. An individual ESA for each experiment helps to focus attention on the experiment, not only during operation in the reactor, but also upon handling, storage, and shipping. A standard hazard classification section in each ESA serves to help assure that individual experiment hazards are not overlooked while in the shadow of a higher hazard category facility.

ATR Safety Basis and PWL Experiments

PWL experiments constitute the primary type of experiments irradiated and handled in the ATR facility. Because of the complexity of the PWL experiments, there are numerous accident conditions that have required assessment. Examination of the list of postulated facility accidents in the ATR DSA reveals that a large percentage of the accidents are associated with PWL experiments. The ATR DSA provides broad coverage of PWL experiment accidents. Consequently, each ESA for a PWL experiment during reactor operation tends to be relatively standardized with little additional evaluation beyond that of demonstrating that the experiment will be operated and handled within the safety envelope already established in the ATR DSA.

Irradiated PWL experiments are routinely inserted into and removed from the ATR. Other experiment transitions also include movements to and from experiment storage locations in the ATR storage canal. These experiment handling evolutions involve lifting, lateral moving, and opening/closing of transfer casks. Figure 4 shows a plan view of the ATR facility with the reactor depicted near the center of the facility. PWL experiment cask handling routinely occurs directly over the reactor and in designated areas adjacent to the reactor. Increased attention to cask drop accidents and associated potential adverse consequences for the fueled reactor during outage conditions has, for example, led to more detailed controls in the ATR safety basis.

PWL experiment coverage in the ATR safety basis naturally affects the USQ process for individual experiments. The USQ process usually only requires a USQ screen for PWL experiments during reactor operation.

ATR Safety Basis and Capsule or Canal Experiments

All ATR experiments are required to meet Plant Protection Criteria identified in the DSA. To assure adequate safety analysis of experiments, the ATR Technical Safety Requirements impose a limiting condition for operation (LCO) stated as follows: "An Experiment Safety Assurance Package (ESAP) shall demonstrate compliance to the ATR Plant Protection Criteria for Condition 1, 2, 3 and 4 faults." The PWL experiments meet the Plant Protection Criteria de facto, for the most part, due to their comprehensive coverage in the ATR safety basis. Capsule and canal experiments, on the other hand, generally require more detailed assessments and/or analyses to demonstrate compliance. The criteria assure necessary experiment safety and yet offer suitable latitude to allow a variety of experiments. These Plant Protection Criteria are abbreviated, for illustrative purposes, as follows:

- Condition 1 (Normal operation) – Radiation exposure limits: 100 mrem/year effective dose equivalent (EDE) and 10 mrem/year EDE from airborne release to off-site public, and 5 rem/year total effective dose equivalent (TEDE) to workers. Reactor fuel source term protection limit: The integrity of the cladding is not challenged except for limited clad defects.
- Condition 2 (Anticipated faults) – Radiation exposure limits: 0.5 rem/year TEDE to off-site public and 5 rem/year TEDE to workers. Reactor fuel source term limit: No rupture of the reactor fuel plate cladding is allowable unless the clad failure is the initiating fault. For canal accidents no melting of the fuel plate cladding is allowed.
- Condition 3 (Unlikely faults) – Radiation exposure limits: 6.25 rem whole body and 75 rem thyroid dose to off-site public and evacuating workers (excluding personnel considered directly at the location of the accident). Reactor fuel source term limit: No large releases of uranium or fission products to the reactor primary coolant system will occur.
- Condition 4 (Extremely Unlikely faults) – Radiation exposure limits: 25 rem whole body and 300 rem thyroid dose to off-site public and evacuating workers (excluding personnel considered directly at the location of the accident). Reactor fuel source term limit: The primary coolant pressure boundary must be maintained (unless this failure is the initiator) and the reactor confinement must not be damaged.

The ATR Plant Protection Criteria provide an example of how a facility safety basis can be designed to accommodate a variety of experiments in addition to those that may be specifically identified and analyzed directly in the safety basis. The versatility of this methodology also has implications for "major modifications" as defined in 10 CFR 830. Designing a safety basis to address facility experiments and incorporating a defined set of corresponding plant

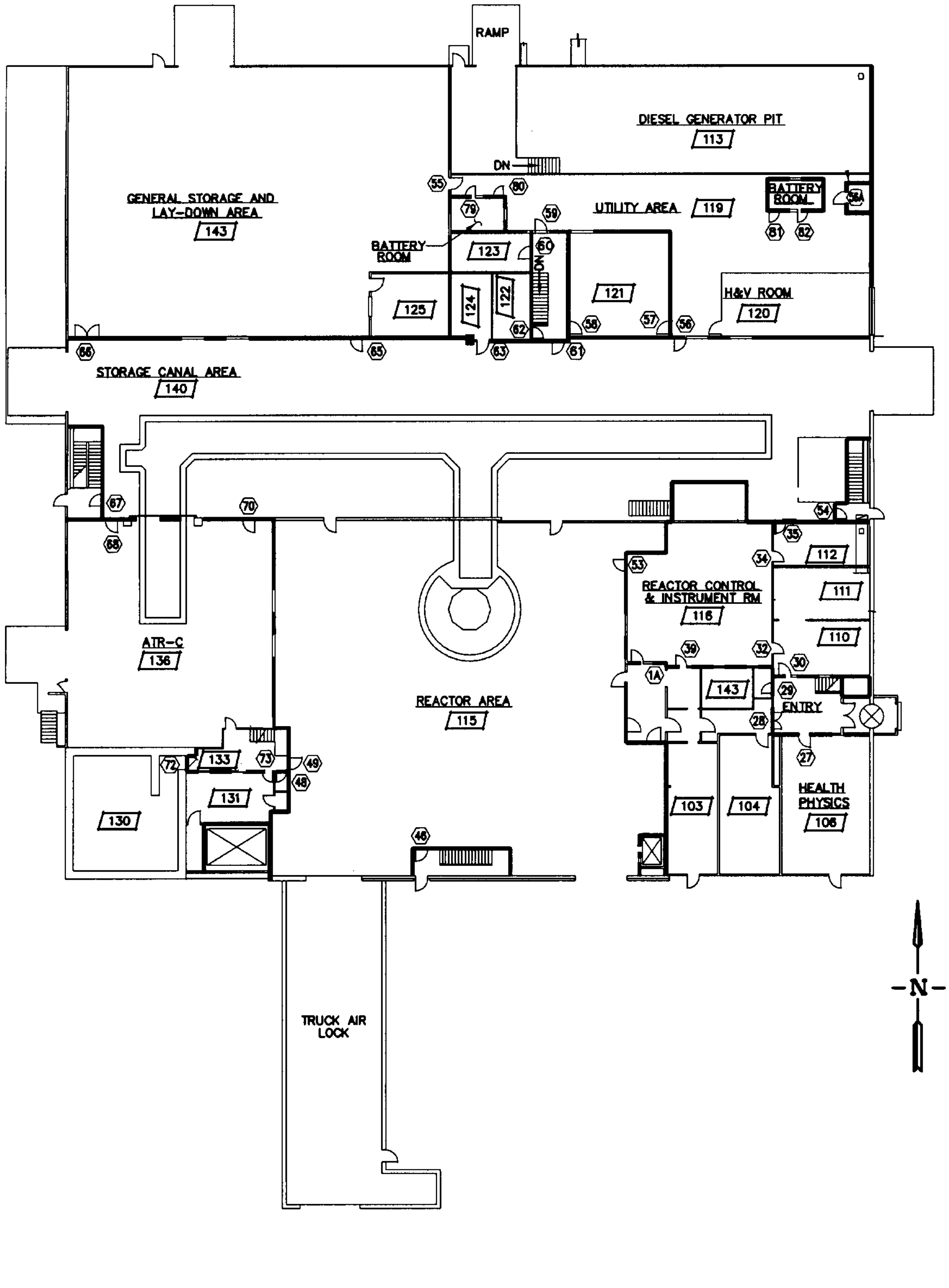

Figure 4. Reactor, Storage Canal, and Adjacent Experiment Handling Areas.

protection criteria make it feasible to install and remove from the facility a variety of experiments without creating “major modifications.”

The USQ process for capsule or canal experiments tends to differ from what is required for the PWL experiments. Since capsule and canal experiments are not addressed to the same degree in the safety basis, the USQ process usually must proceed beyond screening to USQ evaluations. The ESA for a capsule or canal experiment includes documentation of the USQ process.

Capsule and canal experiments also differ from PWL experiments in the areas where experiment handling and storage activities primarily occur. Figure 4 distinguishes the storage canal area from the reactor area. Canal experiments are typically only conducted in the storage canal area and capsule experiments are often stored and prepared for shipment from the storage canal area. PWL experiments are typically only handled and stored in the reactor area. Increased attention to experiment handling activities has revealed ways that experiments can adversely affect the facility, both during reactor operations and during outage conditions.

Conclusions

A 10 CFR 830 safety basis for a test facility can be designed to include appropriate details and controls for baseline experiments, while at the same time allowing for a variety of undefined future experiments. Addressing different experiment types in the safety basis and at the same time imposing general plant protection criteria provides versatility in the experiments that can be conducted.

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